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ABSTRACT

The effects of increasing the load of materials to be moved on rapid movement of these materials were measured using two dependent variables. The first analysis involved overall mean movement time (MT) and segmental movement times. The second analysis dealt with movement time variability evidenced by within subject MT and segmental MT standard deviations. The subjects, six male and six female undergraduate students, completed 60 trials with a linear slide apparatus using six load conditions: zero, two, four, six, eight, and ten kilograms. The measurement interval was 48 centimeters. For both movement time and movement time variability, significant main effects by sex were found. The results indicated that, when movement time increased, the resultant variability of movement time remained constant. Findings were at odds with other research in the area, leading to speculation that an explanation may be obtained from a biomechanical approach. It is concluded that increases in MT, but not necessarily in segmental MT standard deviations, can be expected for submaximal force movements. (FG)

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Paper Presentation

THE EFFECTS OF INCREASING MASS ON THE VARIABILITY OF MOVEMENT & SEGMENTAL MOVEMENT TIMES

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INTRODUCTION

The control of rapid movements is considered the result of motor programs. The structuring, planning and programing of these representations is the responsibility of the decision and effector mechanism. This structuring requires movement considerations or parameters that must be inbuilt features of the programs. Such things as timing and sequencing of events, contractile size, velocity and force are all variables, however, some of these parameters are invariant and required for all motor programs. Summers (1975) reports that the relative timing of events is an essential and integral part of motor programs as the sequencing and timing components of a skill are intergrated and inseperable. He infers that while the overall execution time of a skill may be inputed to the motor program the relative timing is integral and cannot be entered independently of the sequencing. As a result a motor skill may be speeded up or slowed down by the input of overall speed to a motor program but the relative timing of the sequencing of events will remain the same for all speeds. A further conclusion then is that one motor program is used, with all variables constant except the input of skill duration (Schmidt & McGowan 1980; Schmidt & Russell, 1972; Summers, 1975).

Input variables also determine the degree of motor programing. Inertial load and movement amplitude, that is, an increase in load, shorter movement distance and faster speed increase reliance on the motor program as they decrease the possible use of peripheral f eedback (Schmidt, 1982; Summers, 1977). The selection then of the correct input

parameters for a motor program is essential to efficient response. If an error is made in structuring or selection, a new program must be selected and initiated to compensate for these errors. This would require an exit from the motor program and the selection of new parameters or modification in compliance to feedback. For rapid movements of 100 - 200 millisecond major corrections cannot be accomplished, however EMG studies have shown minor adjustments to motor programs are possible by the intrinsic loops (Bizzi et. al. 1976, 1978; Polit and Bizzi, 1978, 1979; Cooke, 1980).

The adjustment and control of these variables is of prime importance in this line of research. Much research is concerned with the capabilities and limitations of movement control experienced by a performer. Interest has been centered on the effects of mass (load), speed (velocity) and accuracy parameters on movement times. An area of current research is the study of these parameters as limitations placed on the control of movements and movement times, from which two distinct and contrasting theories of control have been suggested. They are the mass spring mechanism, derived largely by the work of Bizzi et. al. (1976, 1978), Cooke (1980) and Schmidt & McGowan (1980) and the impulse timing/ variability model as proposed by studies involving the maintenance of gait (Grillner, 1975; Wallace, 1981; Wätzel & Stuart, 1976) complex multicomponent skills (Shappiro, 1977, 1978; Summer, 1975) and rapid movement (Schmidt, Zelaznik and Frank, 1978; Schmidt, Zelaznik, Hawkins, Frank and Quinn, 1979).

The mass spring mechanism refers to the equilibrium obtained by the opposition or stabilizing of agonist and antagonist muscles. An endpoint or new equilibrium point can be achieved by changes in tension to the muscle groups. It is proposed that a motor program designates the required endpoint by specifying muscle length and tension. Experiments (Bizzi et. al. 1976, 1978; Cooke, 1980) have found that even when unexpected loads were added to the movement or in opposition to the movement the limb still moved to intended position. Also if movement was stopped by increased load, upon release, the lim[b] achieved its target (Schmidt & McGowan, 1980). It was also reported by Schmidt & McGowan (1980) that in vertical movements (under influence of gravity) the target was undershot with added load and overshot when load was subtracted. The addition and subtraction of weight did effect the movement time. That is, increased weight increased movement time and vice versa. This infers that if the correct tension information is programed terminal accuracy is ensured and that the mechanism requires no feedback for rapid movements only changes in muscle innervation. In summary a motor program supplies information to the muscle groups that elicit changes in tension which in turn moves the limb to desired endpoint by slip changes in spring constants. This notion is hypothesized for simple unidirectional position responses.

The impulse timing/variability model is related to physical laws and properties in that the combination of time and force produce impulses. This model achieves control of movements by adjusting the impulse parameters, that is, a short duration of maximal contraction will achieve the same force output if the duration is increased and

contraction decreased. Therefore the timing and amount of contraction determine force output and speed of limb movement. The model hypotheses that a motor program provides pulses of motorneurone activity to the musculature which produce contractions. The size of the impulse or the duration of the impulse determine the force and duration of the movement. An unexpected load or time decrease would require a new impulse (motor program) and as such a response to rapid positioning tasks, would result in undershooting of the target. This is considered a result of the innervation patterns supplied by the motor programs in that the motor program determines when to turn off innervation, that is, controls of force and time. This impulse control spreads the force bursts over time to the correct sequence of proper muscles. In conclusion the model infers that the motor program produces impulses that accelerate and decelerate the limb. The size of the impulse, that is, force and/or timing, determines endpoint, velocity of movement and the spatial trajectory achieved (Schmidt, et. al., 1978; 1979).

As with most theories of motor control these notions are in contrast to each other. It seems plausible to suggest that both are on a continuum perhaps at either end, and that neither has total control over any particular type of movement. It may be safe to assume that the control of movement is achieved by a combination of both notions. Once a mode of control is established the movement must operate according to the laws of movement. One such law that has survived examination for at least 25 years is Fitts law, or what has been more commonly referred to as the speed vs. accuracy tradeoff.

Fitts Law. In 1954 Paul Fitts derived a movement law using mathematical constants to explain the relationship found between movement amplitude (A)

and target width (W). Using an experimental paradigm where the subject had to tap a stylus between two targets as rapidly as possible for 20 seconds (with 5% error allowable) Fitts hypothesized from the results, a logarithmic function that describes the relationship between amplitude and target width ($Log_2(2\ A/W)$. This relationship has been referred to as an "index of difficulty" (ID) for limb movement in rapid aiming tasks. When combined with mathematical constants this index reflects average movement time.

$$\overline{MT} = a + b\left[Log_2(2\ A/W)\right]$$

This law depends on the notion of a single channel capacity. That is, as the log increases or ID becomes more difficult more information has to be processed per unit of time. The individual compensates for this increase in information by increasing movement time. This implies an inverse relationship between difficulty and speed, for example, an increased ID decreases speed. In other words the performer trades off speed for accuracy, to hold constant the rate of information processing. Therefore, Fitts law describes the balance between speed and accuracy.

The law has been under critical review recently and although many previous studies have established a generality of the law across age, limbs, size of movement, movement environment and tasks, an exception to the rule has been proposed.

Recent studies (Sherwood and Schmidt, 1980; Schmidt, et. al. 1978, 1979) have reported that a linear and proportional relationship exists between force, and force variability and that movement time variability does not hold for loads that result in 65% or greater maximal efforts or

contractions. In fact it has been shown that movement time variability decreases when movements were kept to 150 milliseconds and load was increased. The increase in load increases the number of contracting units with maximal contractions resulting in a reduction of movement errors due to the reduced variability of muscle activation. The inference follows that maximal effort may lead to a reduction of timing errors, hence an increase in accuracy. If true, this notion is in direct contradiction to the speed accuracy tradeoff proposed by Fitts.

The speed accuracy tradeoff has long been the cornerstone of the motor control area, as it has provided a simple and general explanation of experimental results. However, more recent notions have tended to depart from Fitts law under certain conditions. Sherwood and Schmidt (1980) and Schmidt et. al. (1978, 1979) have shown that under conditions of 65% maximal contraction load, that the variability of movement time decreases resulting in a lesser degree of timing error. If this is so, what then will happen to accuracy if we add a parameter of maximum speed. The notion being that if indeed maximal load decreases v a riability that maximal speed will induce maximal contraction and will also decrease variability or timing error. This being the case, the contrast to Fitts law of speed accuracy would be contradictory, in that certain parameters of movement conditions do not support the speed v. accuracy tradeoff.

This creates problems for the performance of coincidence timing tasks. In particular, the practical applications of such research for learning. For instance, the learning of a tennis stroke or baseball hitting may well be enhanced by the use of a heavier racket or bat and maximal (contractions) by faster swing movements. If so, is there an

optimal level for load and velocity parameters for efficient movement. It may well be that the 65% level of force indicated by Sherwood and Schmidt (1980) is the apex of an inverted "U" model for rapid movement efficiency.

The purpose of this study was to determine if associated movement time variability could be altered. Generally research has suggested that movement time variability decreased as movement time decreases. Sherwood and Schmidt (1980) suggest that near maximal impulses reduce the variability of force products. This study was concerned with the effects lengthening movement times have at the variability of movement times when maximal efforts are made.

METHOD

[redacted]

Subjects. Twelve students (6 males, 6 females) enrolled in the undergraduate motor learning class at California State University, Long Beach, served as subjects. All subjects were volunteers who received class credit for participating. All subjects were right handed and had no previous experience of the required task. Subjects ranged in age from 20 - 29 years.

Apparatus. The apparatus consisted of a linear slide mounted on a table (dimensions 0.749 m. high, 0.787 m. wide and 1.549 m. long) with a capacity for timing segmental movement times and overall movement time (Figure 1). A wooden slide was mounted on two 2 cm. roller bushes

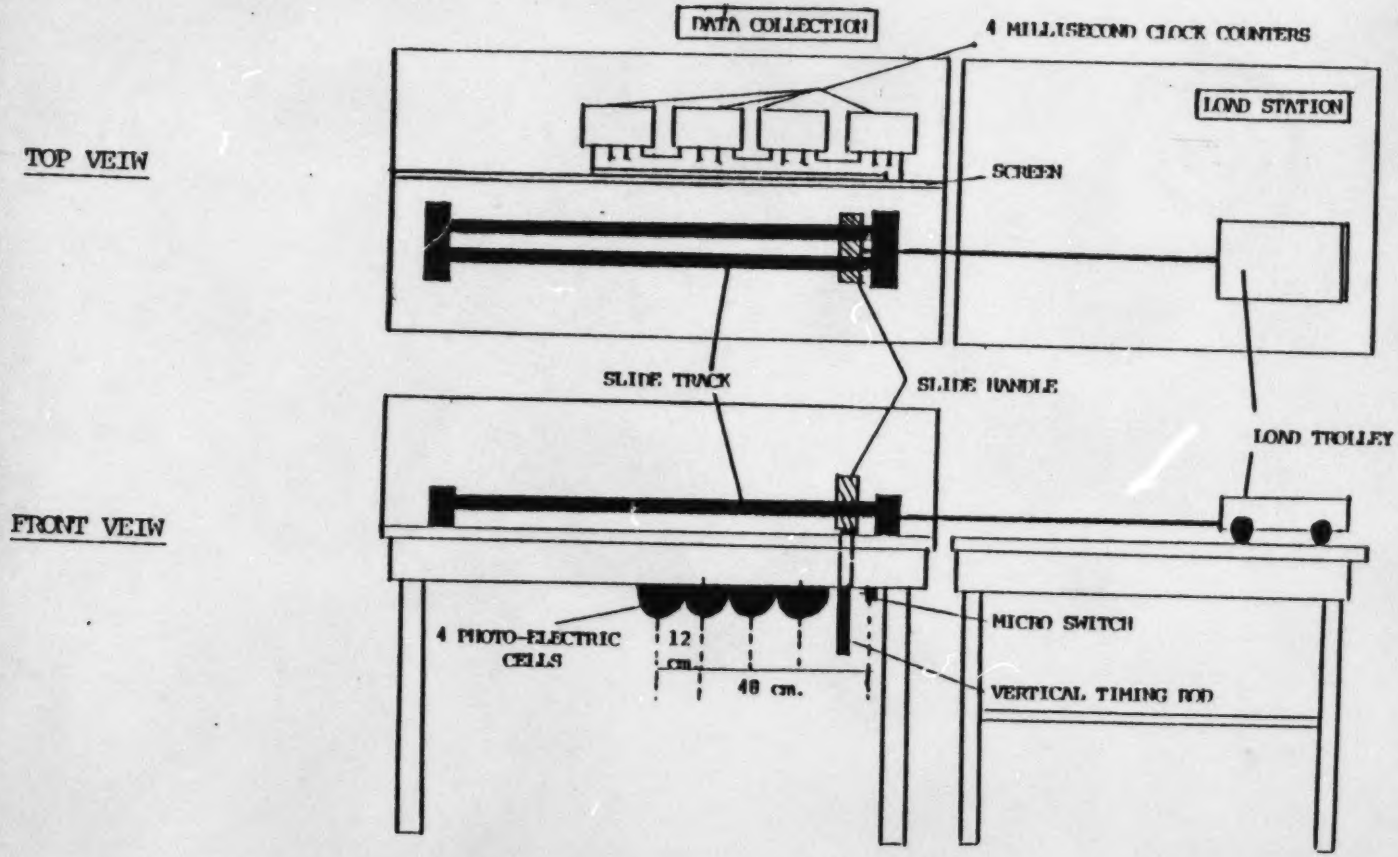

FIGURE 1 Plan diagram of linear slide apparatus, timing circuit and load vehicle.

(King Bearing Co.) to enable lateral movement on two 2 cm. cold steel rods. A parallel slot was cut in the table directly below the rods which permit a 30 cm. vertical rod to transverse the distance of the slide. The vertical rod (attached to bottom of slide) was designed to open and close a timing circuit that was attached underneath the table. The circuit consisted of one reed switch (start) and four Lafayette photo electric cells (stop) (serial#/63501 & 63502) placed 12 cm. apart, which were connected to one of four Lafayette millisecond clock counters (serial#/54519-A) each connected in series. Movement of the vertical rod would break the first reed switch and open the circuit. As movement continued the rod broke the beam emitted from the light source of each of the photo electric cells and stopped the respective clocks. The first three clocks measured the segmental movement times and the fourth measured overall movement time. The measurement interval from start (reed switch) to finish (last photo electric cell) was 48 cm. in length.

Load was applied to the slide by means of a weight bearing free wheel trolley. The trolley was attached to the slide by a 1 cm. cold steel rod, that ran parrallel, in line and between the supporting slide rods. Movement of the slide pulled the trolley across an adjoining table.

Design. Subjects completed 60 trials within a sex by load paradigm. Six load conditions of 0, 2, 4, 6, 8 and 10 kg. were used (10 trials for each load condition). Presentation of load was progressive and counter-balanced by subjects.

Procedure. Upon entering the testing room, subjects were asked to kneel on a floor mat in front of the apparatus so that they were centered directly opposite the finish line. The slide handle was grasped firmly

in the right hand, the left hand was placed flat on top of the table. Subjects were instructed to move the handle along the slide from right to left as quickly as possible in a continuous movement past the finish line (48 cm. from start). They were informed that six load conditions would be used.

A block of 10 trials was conducted for each load condition and subjects were informed when the load was changed. Each trial was initiated by the subjects in their own time.

Data sheets were prepared to record subject age, sex and load, the four segmental movement times and the overall movement time. Data was collapsed across trials and computed on the Cyber 750 system in conjunction with the Social Sciences Statistical Package (SPSS) and the Bio Medical "P" Series Software Packages.

RESULTS

Results determined the effects of increasing load on rapid movements, with movement speed as rapid as possible. Two dependant variables were measured. The first analysis involved overall mean movement time (MT) and segmental movement times (MT_S). The second analysis dealt with movement time variability evidenced by within subject MT and segmental MT standard deviations (SD_{MT}).

Data was analyzed on the Cyber 750 computor system with the Statistical Package for the Social Sciences and Biomedical "P" series software packages. Analysis was conducted by collapsing MT scores

across trials for the calculation of the dependant measures, mean movement time (MT), mean segmental movement times (MT_s), variability of movement time (SD_{MT}). Analyses of variance were conducted to determine significant main and interaction effects. Post hoc analyses were performed, employing Tukey mean separation tests. An a priori level of significance was set at 0.05 for all analyses.

Movement Times. Movement times (MT) and segmental movement times (MT_s) were recorded for each trial. The main MT and MT_s were calculated for each subject and load condition. A 2 x 6 (sex by load) analyses of variance with repeated measures on the last factor was performed to determine their (independant variables) effects on movement time. Significant main effects for sex, $F(1,10)= 15.77$, and loads, $F(5,50)= 53.58$ were established. However, no significant interaction was observed for the sex by load $F(5,50)= 1.59$. Post hoc analysis indicated that males (254 milliseconds) were significantly faster than females (352 milliseconds). Also that increased loads displayed significant by slower MT except for the 10kg. load which was the same as the 6 or 8 kg. conditions (Figure 2).

Similar 2 x 6 (load by sex) analyses of variance with repeated measures on the last factor were performed for the four segmental MT. In general sex displayed significant differences for all segments (Figure 3) except segment 4 (F Range 32.2 - 60.1). Loads also significantly affected MT (Figure 4) for all segments (F's 57.24 - 11.6). Post hoc analyses demonstrated that the MT for females were slower than males and that as load increased so to did MT. An exception was evident for segment one where a significant sex by load interaction was established,

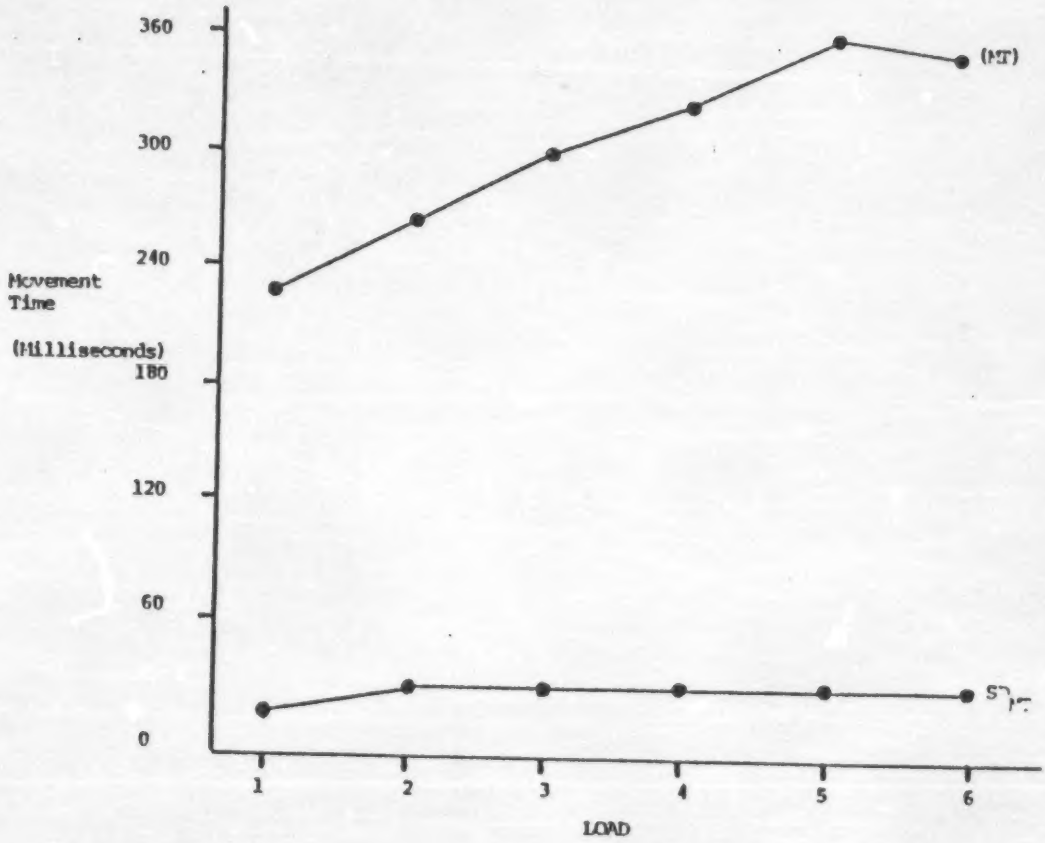

FIGURE 2

Mean Movement Time (MT) and Movement Time Variability SD for Load Conditions.

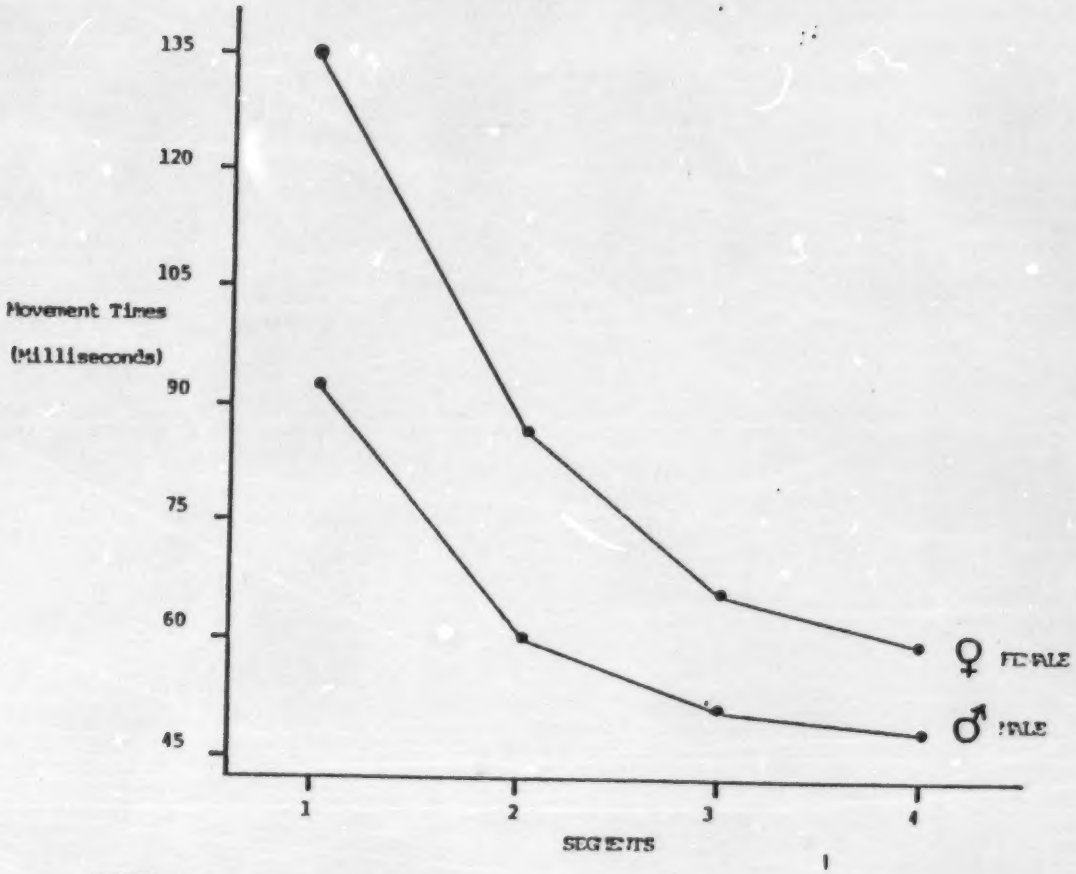

FIGURE 3

Mean Segmental Movement Time for Sex

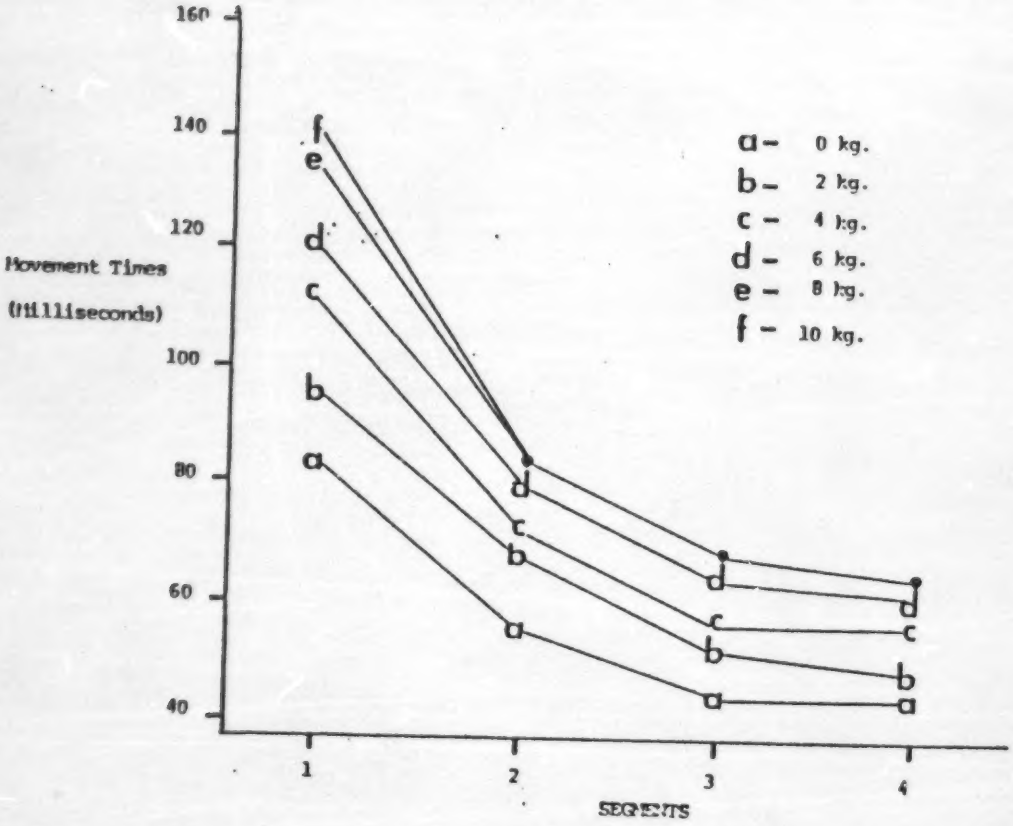

FIGURE 4

Mean Movement Times by Loads for Segments.

$F(5,50) = 2.65$. The interaction was a result of faster movement of the 10 kg. load than the 8 kg. load by females. This may also account for the apparent decrease in MT between the 8 kg. and 10 kg. load conditions.

Movement Time Variability. Determination of MT effects on MT variability (SD_{MT}) for both MT and MT_s was accomplished by analyses of variance, identical to MT analysis, performed on the within subject variability. A sex only significant main effect was revealed $F(1,10) = 11.14$. Post hoc analyses indicated that females were more variable (28 milliseconds) than males (11 milliseconds) in movement production (Figure 5).

The lack of significant load main effects for SD_{MT} is puzzling. Since loads are associated with MT. One may have expected an increase in SD_{MT} as MT increased. However, this increase is not evident by evaluation. *

The analyses for SD_{MT} for segmental MT also found sex only significant main effects (Fs range 10.1 - 5.1). Females were more variable than males. Evaluation of SD_{MT} for loads revealed no significant differences. However, an interesting point to note is the change in variability across segments, in particular the great SD_{MT} of initiation (Figure 6). The first segment displayed very high SD_{MT} for the 10 kg. condition which decreased across segments to achieve the least SD_{MT} in segment four. Decreasing loads did not produce consecutive decreased amounts of SD_{MT}.

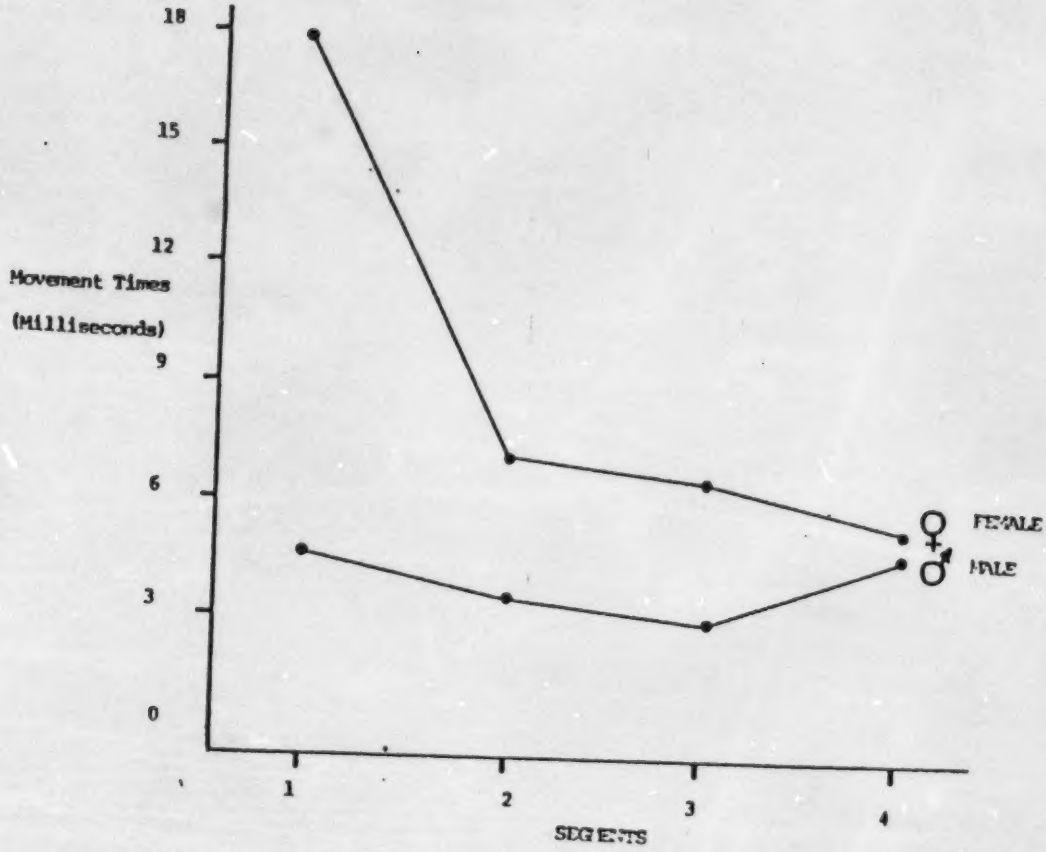

FIGURE 5

Standard Deviations of Segmental Movement Times by Sex

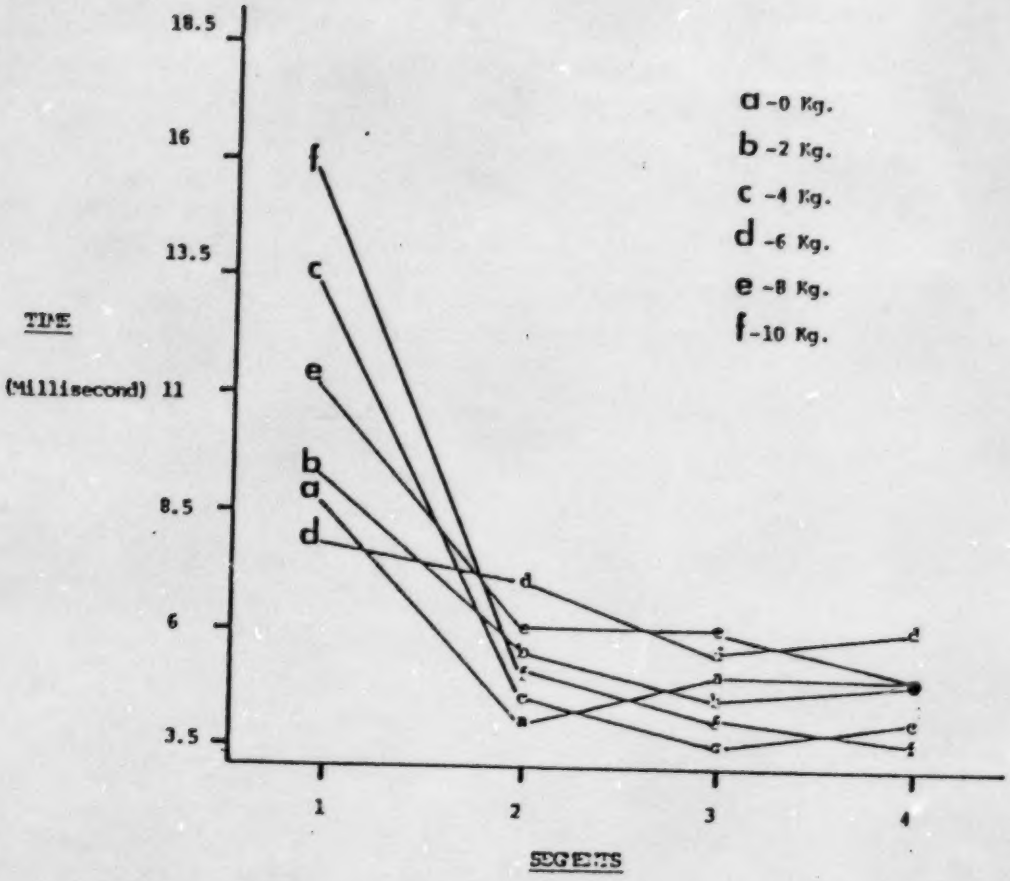

FIGURE 6

STANDARD DEVIATIONS OF SEGMENTAL MOVEMENT TIMES BY LOADS.

DISCUSSION

A basic postulate of the impulse variability model (Schmidt, Zelaznik, Hawkins, Frank and Quinn, 1979) implies that temporal elevations of impulses are directly associated with the stability of the movement. The results of this experiment do not support this basic and fundamental principle. The results indicated that when movement time (MT) increased the resultant variability of movement time (SD_{MT}) did not vary, but remained constant. In terms of the impulse variability model the resultant constant SD_{MT} can be viewed as an apparent proportional reduction of SD_{MT} as MT increased.

A possible argument against this type of finding might center on the notion that impulse durations were constant for all of the movements. That is in movements of a kinetic nature (as opposed to spring loaded that result in constant tension) once inertia is overcome the momentum of the load will carry the movement through allowing the impulses to cease, OR BE MINIMAL. Impulse durations would then be constant across all movement time conditions and result in relatively equal variability. If such was the case in the current study a deceleration pattern should have been observed at some point in the movement. The results of the segmental movement time analyses, however, indicated that acceleration existed throughout the course of the movement. Obviously the acceleration could only have been caused by a continued firing of the motor impulses associated with the movement.

These findings may be explained as a result of maximal force production in movements negating the effects associated with impulse

duration. This explanation is derived from the work of Sherwood and Schmidt (1980) in that a force that exceeded 65% maximum displayed a decrease in the variability of force outputs. Also, when the force output was increased a decrease in SD_{MT} was observed.

Recent research (Northam & Shea, Note 1) however, has failed to replicate the findings of Sherwood and Schmidt (1980) as no decrease in SD_{MT} can be duplicated. If there is no resultant decrease in SD_{MT} another explanation needs to be proffered for the findings of this experiment. Since results do not support the notion of a direct relationship between impulse durations and SD_{MT}.

A plausible explanation then may be obtained from a biomedical approach. The initial movement segment displayed greater variability and slower mean movement times which indicated a period of movement initiation where inertia of load had to be overcome. The observed additional and subsequent acceleration patterns across segments was a result of repeated impulse firings. Biomedics suggest that due to the kinetic nature of the task, once inertia is overcome, inpulses need not be maximal to produce a movement acceleration. This suggests that in submaximal movements, in which force production was constant, that there would be no significant changes in variability of movement time. It would be logical then to suggest that SD_{MT} is closely related to force outputs and not impulse durations. This may be observed in an analogy of a golf swing. If an expert golfer has to hit a ball 200 meters, he does not select a driver, with which he can hit 250 meters, and attempt to work sub-maximally, or use a different swing, as this introduces

variability to the result. Instead, he selects a club which will produce the desired endpoint by use of a consistant force swing. That is, the golfer keeps his swing consistant at the same speed and force and to achieve different results, changes clubs to suit (3 iron-200 meters; 5 iron-160 meters). In this way force outputs are changed by club size and mass. The variability then, is reduced by performing consistantly for each swing and the addition of load or mass (larger club eg. driver) simply serves to increase the MT. In fact, as long as force outputs are consistant there would be no reason to suspect an increase in SD_{MT} associated with an increase in MT. This would suggest that as long as impulses produce consistant force outputs there would be no associated increase in SD_{MT} as MT increases. The golf analogy implies that consistant effort or force produces a reduction in SD_{MT} as it is easier to swing maximally consistantly than to attempt a sub-maximal swing. Even though it was reported (Sherwood and Schmidt, 1980) that 65% or greater force outputs reduce variability, it is suggested that for a reduction in SD_{MT} it is better to perform at a near maximal effort consistantly than at varied sub-maximal efforts.

Such an implication points to a performance disadvantage. Even though performance at maximum is easier and reduces variability there is only one opportunity to correct the movement for a detected error. Movement then, can only be corrected by a deceleration or a reduction of effort and force outputs. This does not seem to be a great problem as a reduction of variability (Sherwood and Schmidt, 1980) and increased spatial accuracy (Schmidt and Sherwood, 1982) are a result of maximal

efforts. However, from a purely behavioral approach to performance this may be outweighed by the previously mentioned disadvantage. Also that a maximal effort results in a decreased movement time. Such a decrease lessens the time available for detection and correction of error by feedback. To increase the opportunity for feedback a sub-maximal effort would be required, this would produce a more variable movement but perhaps create an advantage. The advantage being that at a sub-maximal performance would not only allow more time for detection and correction but allow correction by acceleration or deceleration of movement by increasing or decreasing force outputs. If however, the subject can learn to perform consistantly at this sub-maximal level he will not only have the advantage of time, but be able to keep SD_{MT} near constant for all movements.

Summary. The finding of significant sex differences is not surprising if explained as a result of physical strength characteristics. However, females are able to move just as maximally as males therefore MT and SD_{MT} should produce the same results as males. The fact that there is a difference suggests perhaps a difference in power and force outputs between males and females. This experiments did not provide data for force and power outputs. Perhaps then a point for future research would be the measurement of force and power outputs and to ascertain if the pretraining of females would result in a past test difference between males and females.

The inverse relationship of speed versus accuracy is not apparent in this paradigm, where the dependent variables are MT and SD_{MT}, as no change in SD_{MT} is evident or can be associated to changes in MT. This finding

supports the notion of a direct relationship proposed by Newell et. al. (1979).

In conclusion, it is also apparent that increases in MT, but not necessarily SD_{MT} can be expected for sub-maximal force movements, which is contrary to the impulse variability model of Schmidt, et. al. (1978, 1979). Variability then appears to be associated with the amount or consistancy of force outputs than the duration or intensities of impulse firing involved in movement production.

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